

ICAN/PART: Particulate Composite Analyzer, User's Manual and Verification Studies

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ABSTRACT

A methodology for predicting the equivalent properties and constituent microstresses for particulate matrix composites, based on the micromechanics approach, is developed. These equations are integrated into a computer code developed to predict the equivalent properties and microstresses of fiber reinforced polymer matrix composites to form a new computer code, ICAN/PART. Details of the flowchart, input and output for ICAN/PART are described, along with examples of the input and output. Only the differences between ICAN/PART and the original ICAN code are described in detail, and the user is assumed to be familiar with the structure and usage of the original ICAN code. Detailed verification studies, utilizing three dimensional finite element and boundary element analyses, are conducted in order to verify that the micromechanics methodology accurately models the mechanics of particulate matrix composites. The equivalent properties computed by ICAN/PART fall within bounds established by the finite element and boundary element results. Furthermore, constituent microstresses computed by ICAN/PART agree in an average sense with results computed using the finite element method. The verification studies indicate that the micromechanics programmed into ICAN/PART do indeed accurately model the mechanics of particulate matrix composites.

INTRODUCTION

Currently, there is a growing interest in the use of particulate reinforced composites in many different areas of the engineering industry. These types of composites are useful for circumstances where a multi-phased material is desired, but the costs and fabrication difficulties involved in manufacturing a continuous fiber reinforced composite are too high. Particulate reinforced composites can also provide

much of the increase in stiffness and strength as compared to monolithic materials as is seen in continuous fiber reinforced composites. The particle reinforced matrix can also be used as the matrix material in a continuous fiber reinforced composite, providing even greater increase in stiffness and strength over monolithic materials. One well known example of a particulate reinforced composite is concrete. The goal of this work is to describe a computationally efficient computer code which can be used by engineers in both aerospace and non-aerospace fields to characterize and design particulate reinforced composites.

Several different analytical methods, such as bounding techniques and numerical analysis methods, have been utilized previously to analyze particulate reinforced composites [1]. However, each of these techniques have significant limitations, either in terms of the tightness of the bounds in the bounding techniques, or the difficulty in model generation and computational expense found in the numerical analysis techniques. Thus, the need still exists for a more accurate and computationally efficient analysis technique which can be utilized for routine parametric studies and/or embedded into global structural analysis methods. This analysis method must be able to quickly and accurately compute effective properties and local behavior such as microstresses for particulate reinforced composites.

At NASA Lewis Research Center, research has been conducted for over twenty years in the application of micromechanics techniques to the analysis of composite materials. The goal of micromechanics is to compute the effective properties of the overall composite based on the properties and concentration level of the constituent materials. In one such method developed at NASA Lewis, simplified micromechanics equations have been derived for continuous fiber reinforced polymeric matrix composites based on a mechanics of materials approach. These equations have been embedded into the ICAN (Integrated Composite Analyzer) computer program [2]. ICAN predicts effective mechanical and thermal properties, as well as the average state of stress (microstresses) in each constituent due to a variety of loading conditions. Environmental factors such as temperature and moisture are also accounted for in the simplified micromechanics equations. The advantage of this methodology is that the equations are in closed-form and do not require any numerical integration, thus promoting significant computational efficiency.

The objective of this work is to describe the modifications that have been made to the ICAN code in order to allow it to predict the effective properties and microstresses of a particulate reinforced composite. This modified version of ICAN is referred to herein as ICAN/PART (Integrated Composite Analyzer-Particulate Reinforced Composites). ICAN/PART has the capabilities to compute the effective properties and microstresses in a particulate reinforced composite, as well as a fiber reinforced composite which has a particulate reinforced matrix material. The complete derivation details of the micromechanics based equations for effective properties and

microstresses are described in a companion report [1].

In the beginning of this report, the flow chart, features and capabilities of the original ICAN are reviewed. The modifications to the flow chart resulting from the changes made for ICAN/PART are then reviewed. Details of the code usage, input deck, resulting output, and material databank are then described, complete with sample input and output descriptions. This section serves as the user manual for the ICAN/PART computer program. Only the differences between ICAN/PART and the original ICAN code are described in detail, and the user is assumed to be familiar with the structure and usage of the original ICAN. To provide preliminary indications of the accuracy of the formulation, verification studies are then presented in which the effective mechanical and thermal properties, as well as microstresses, are computed for a representative particulate reinforced composite system. The results computed using ICAN/PART are compared to results obtained by using three-dimensional finite element and boundary element analyses.

ICAN COMPUTER CODE DESCRIPTION

The original ICAN computer code [2] combines the simplified micromechanics equations developed at NASA Lewis Research Center and standard laminate theory [3] into one integrated computer code. ICAN can be used to conduct linear analyses of multilayered continuous fiber reinforced polymeric matrix composite systems.

Within ICAN, the effective properties of the composite ply, with temperature and moisture effects included, are computed from the constituent properties using the simplified micromechanics equations [2]. Standard composites, as well as interply or intraply hybrid composite systems (where more than one type of fiber is present in a composite layer) can be analyzed. Once the ply properties are computed, standard laminate theory is used to obtain the effective properties for the overall composite. In a composite laminate, the various plies can be oriented at different angles, which is accounted for in the laminate theory. While the temperature and moisture of each ply is assumed to remain constant through the thickness of the ply, the temperature and moisture content of the different plies can vary, allowing the presence of thermal and/or moisture gradients through the thickness to be incorporated into the analysis. Once the effective properties of the composite laminate are computed, these properties can be utilized as element/nodal properties in a finite element analysis. Once the response at a point is determined by the finite element analysis, the computed membrane and bending loads can be entered into ICAN, and the equivalent response and stress state at the laminate, ply and constituent level can be computed. The response at the laminate and ply level is determined through the use of laminate theory, and the microstresses at the constituent level can be computed by using the simplified micromechanics theory. A flowchart of this process is shown in Figure 1. Full details of the micromechanics equations and the analysis process and procedure

can be found in the ICAN User's Manual [2].

Input to the ICAN code includes composite geometry, including ply/layer lay-up, fiber volume ratio, thickness and orientation of the layers. Additionally, code names for the constituent materials, factors reflecting the fabrication process and the loading conditions are specified. The constituent material properties are read in from a dedicated databank using the specified fiber and matrix code names as identifiers. Commonly available fiber and matrix properties are included in the databank. Alternately, the user can easily enter new sets of materials and material properties into the databank.

The output generated by the ICAN computer code includes the various ply and composite effective properties, composite structural response and composite stress analysis response with details of failure. Also computed are the microstresses in the constituents and different regions of the unit cell. Additional features unique to ICAN include ply stress-strain relations, stress concentrations around a circular hole, free-edge stresses, material property cards that can be utilized in general purpose finite element codes such as MSC/NASTRAN or MARC, failure loads based on the maximum stress criterion, and laminate failure stresses based on first ply failure. The output can be tailored by the user through the selection of output options in the input file.

ICAN/PART Code Development

This section describes the details pertaining to modifications done to the original ICAN code in order to make it applicable to particulate matrix composites. Specifically, the flow chart of the modified program, the code usage including a description of the input and sample input data sets, a brief description of the output details specific to the modified part of the code and details of compiling and executing the code on UNIX based workstations are presented in some detail. Details on the micromechanics equations utilized in ICAN/PART and their derivation can be found in a companion report [1]. As mentioned earlier, this section assumes that the user is familiar with the structure and usage of the original ICAN code, and has the user manual for this code available [2].

Flow Chart

Parts of the flow chart pertaining to the modifications done to the original ICAN are shown in Figure 2. The flowchart focuses on details pertaining specifically to the analysis of particulate matrix composites.

As shown in Figure 2, first the input data, including the Boolean identifying that the analysis is for a particulate matrix composite, is read in. As part of the input, data regarding the constituents of the particulate matrix and the particle volume fraction is

read into the code. If the analysis is for a particulate matrix composite, several steps are carried out. First, the particle and binder properties for the particulate reinforced matrix are read in from the material database. Next, the constituent properties that have been read in from the database are echoed to the output file in a readable format. Once the constituent properties have been read in, the effective properties of the particulate reinforced matrix material are computed using the equations discussed in reference [1]. The computed effective properties of the particulate reinforced matrix are then put into the proper format and assigned to be the constituent properties for the "matrix" of the overall material system, to be used in later parts of the computer code. At this point, the code checks to see if a significant volume fraction of continuous reinforcing fibers (greater than 1%) is present in the overall material system. If continuous fibers constitute a significant volume fraction of the composite, the constituent properties for the reinforcing fibers are read in from the material database. If the "composite" is only composed of the particulate reinforced matrix, a "fiber" is assigned to the composite with a very small volume fraction, and the same properties as the particulate reinforced matrix. This approximation is required since ICAN always requires a "fiber" to be present for the analysis.

If the material to be analyzed is not a particulate matrix composite, the fiber and matrix constitutive properties are read in from the material database just as in the original ICAN code. In either case, once the fiber and matrix material properties are assigned, the overall composite effective properties are computed, and the code follows the original ICAN until the ply microstresses are computed.

The computation of the ply microstresses, including the breakdown into fiber and matrix microstresses, is carried out just as in the original ICAN. However, if the material is a particulate matrix composite, the matrix microstresses are smeared quantities at this point, with no breakdown into binder and particle microstresses. If the material is a particulate matrix composite, the matrix microstresses are summed up and utilized in the equations described in reference [1], which breaks the overall matrix stresses down into binder and particle microstresses. The computed particle and binder microstresses, including directional and Von Mises stresses, are then printed out to the output file. The microstresses due to mechanical and thermal loads are summed together and are printed as one quantity. Also, if significant continuous reinforcing fibers are present in the composite, the microstresses are divided into the "A" and "B" regions of the cross section, as is described in the user manual for the original ICAN code [2].

Once the particulate matrix microstresses are computed and printed, code execution and output continues identically to the original ICAN.

Code Usage

The usage of ICAN/PART is quite similar to that of the original ICAN, with the following exceptions as described below. The ICAN user manual [2] should be referred to for additional details pertaining to the standard ICAN input. The following applies only to changes from the standard ICAN input. One important point to note is that all of the material property and load data should be specified in English units. This specification is identical to that found in the original ICAN. A table of units for the various properties is provided at the beginning of each ICAN/PART output.

A.) In the Booleans Card Group, two new Booleans are required:

MICRO: The letter T is entered if a full micromechanics analysis is to be performed. If the letter F is entered, the code will assume that ply level properties are to be read from the databank, and no micromechanical calculations are to be performed. For the full analysis of a particulate matrix composite, this Boolean should always be set to T.

PARTIC: The letter T is entered if the composite to be analyzed is a particulate matrix composite. The letter F is entered if the composite does not have a particulate reinforced matrix. Note that if the letter T is entered here, indicating a particulate matrix composite, all of the material systems of the composite must be specified as having a particulate reinforced matrix.

B.) Particulate Constituent Information:

After the Boolean card group, if the composite to be analyzed is a particulate matrix composite, an additional input card describing the constituents of the particulate reinforced matrix is required. The information to be given for this input card is the four letter code name for the particle, the four letter code name for the binder, the particle volume ratio (as a decimal number, not a percentage), and the void volume ratio. The code names for the particle and the binder are utilized to correctly read in the material properties from the material databank. The currently available materials and their four letter code names are listed in a later section which describes the material databank in more detail. Only code names which are incorporated into the material databank can be utilized. Currently, the analysis assumes that no voids are present in the particulate matrix, but a number for the void volume ratio still must be entered as a placeholder. The FORTRAN format for this information is 2A4,2E8.2. An example is as follows:

PARFIMHS 0.3 0.05

where PARF is the four letter code name for a particle (Particulate Filler in this case), IMHS is the code name for a binder (Intermediate Modulus High Strength Matrix), 0.3 is the particle volume ratio (30%), and a placeholder value of 0.05 is entered for the "void volume ratio". Note that there are five (5) spaces between the binder code name and the particle volume ratio value, and that there are four (4) spaces between the particle volume ratio value and the void volume ratio value, in keeping with the required FORTRAN input format. Please note that currently one (1) particulate matrix system can be defined per analysis.

C.) Laminate Configuration Definition:

The input for ICAN/PART for this data is identical to that of the original ICAN. Note that the equations defining the effects of moisture in a particulate matrix composite need to be further refined and verified. Therefore, it is highly recommended that a moisture content of zero (0) be defined for all plies. However, the equations which compute the effects of temperature on the binder properties in a particulate matrix composite have been fully implemented and tested. Therefore, a use temperature other than 70° F can be utilized, and the degradation of the binder properties due to temperature will be correctly computed. Examples of the effects of matrix degradation on the binder properties will be shown later in the example output section.

D.) Material Systems Information:

The material system input for ICAN/PART is similar to that of the original ICAN code, with the following exceptions. First, if a particulate matrix composite is to be analyzed, the composite matrix for all of the material systems must be a particulate matrix. The matrix material must be composed of the material defined in the particulate constituent information described above. In the material systems input cards, the four letter code word "COMP" must be entered for the matrix material. In the code execution, the information provided in the particulate constituent information cards will be utilized to compute the effective properties of the overall particulate matrix, and this information will then be utilized by the code to represent the properties for the overall composite matrix (instead of reading in the overall matrix information from the constituent databank). One note of caution is that several material systems can be specified for an analysis, with differing fibers for each material system, however the "COMP" matrix must be specified as the matrix material for all of the material systems.

For the fiber entry for the material system, two options are available. First, if the particulate matrix is to be reinforced by continuous fibers, such as reinforcing concrete by steel beams, the four letter code name and fiber volume ratio of the fiber should be entered in the appropriate places on the input line. Please note, however, that if a particulate matrix composite is to be analyzed, hybrid composite plies are not

permitted, and zeros (0) should be entered for the secondary fiber volume ratio and secondary composite volume ratio values.

If the material system is to consist of the particulate reinforced matrix only (i.e. no continuous fiber), then the following procedure should be followed. For the four letter code name for the fiber, the word "COMF" should be entered. For the fiber volume ratio, a positive number less than 0.01 (but greater than 0.0001) should be entered. A good value to use is 0.0050. With this procedure, the "fiber" of the composite will then be assigned the properties of the particulate matrix computed earlier. This procedure is needed since the original ICAN code was written to analyze composites with continuous fibers, and thus a "Fiber" material must be specified and accounted for in the input. The computed ply and laminate effective properties will then be equal to the effective properties computed for the particulate matrix.

E.) Sample Input:

The following four sample input files are designed to show some of the code features. Features of input specific to ICAN/PART are discussed below in some detail.

Example 1: In this input, a particulate matrix composite is to be analyzed (PARTIC is set to T). The particulate matrix consists of Particulate Filler Particles (PARF) in an Intermediate Modulus High Strength Matrix. The particle volume ratio is set to 0.3 (30%), and a placeholder value of 0.05 is entered for the void volume ratio. In the material system, only one material system is specified, and this material system is to consist of the particulate matrix only (no continuous fiber is present). Therefore, the "COMF" code is entered for the "Fiber", the "COMP" code is entered for the "Matrix", and a "Fiber Volume Ratio" of 0.005 is entered. Please note that temperature loads are applied in this input by specifying differing use and cure temperatures for this ply, and that an axial membrane load is applied in the "X" direction in the mechanical load section of the input.

```
ICAN verification 1 for particulate composite
COMSAT      T
CSANB       F
BIDE        F
RINDV       F
NONUDF      T
DEFECT      F
$
$ MICRO: T=Full Analysis of Particulate Matrix Composite
$        F=No Micromechanical Calculations Performed
$
$   MICRO      T
$
$ PARTIC: T=Particulate Matrix Composite
$        F=Homogeneous Matrix Material
$
$   PARTIC     T
$
$ Material Cards for Particulate Matrix:
$   PARF=Particle Code Name for Particulate Matrix
$   IMHS=Binder Code Name for Particulate Matrix
$   0.3=Particle Volume Ratio
$   0.05=Void Volume Ratio (Placeholder Only)
$
$ PARFIMHS    0.3    0.05
$   PLY       1      1   70.00  170.00   0.00   0.00  0.1
$   PLY       2      1   70.00  170.00   0.00   0.00  0.1
$   PLY       3      1   70.00  170.00   0.00   0.00  0.1
$   PLY       4      1   70.00  170.00   0.00   0.00  0.1
$
$ Material Cards for Particulate Matrix Composite
$   COMF=Code Name for "Fiber" With Same Properties as Particulate Matrix
$   COMP=Code Name for Particulate Matrix
$   0.005="Fiber" Volume Ratio (Set Very Small Since No Continuous Fiber)
```

```

$
MATCRD      1COMFCOMP  0.0050  0.0000COMFCOMP  0.0000  0.0000  0.0000
PMEMB      170.4      00.0
PBEND       0.
PTRAN       0.
PRINT       ALL

```

Example 2: This input file is identical to the previous input file, with the exception that only thermal loads are applied to the composite in the form of a temperature cool-down from 170 degrees F to 70 degrees F.

```

ICAN verification 2 for particulate composite
COMSAT      T
CSANB       F
BIDE        F
RINDV       F
NONUDF      T
DEFECT      F
$
$ MICRO: T=Full Analysis of Particulate Matrix Composite
$        F=No Micromechanical Calculations Performed
$
$   MICRO      T
$
$ PARTIC: T=Particulate Matrix Composite
$        F=Homogenous Matrix Material
$
$   PARTIC      T
$
$ Material Cards for Particulate Matrix:
$   PARF=Particle Code Name for Particulate Matrix
$   IMHS=Binder Code Name for Particulate Matrix
$   0.3=Particle Volume Ratio
$   0.05=Void Volume Ratio (Placeholder Only)
$
PARFIMHS     0.3    0.05
PLY          1      1    70.00  170.00    0.00    0.00  0.1
PLY          2      1    70.00  170.00    0.00    0.00  0.1
PLY          3      1    70.00  170.00    0.00    0.00  0.1
PLY          4      1    70.00  170.00    0.00    0.00  0.1
$
$ Material Cards for Particulate Matrix Composite
$   COMF=Code Name for "Fiber" With Same Properties as Particulate Matrix
$   COMP=Code Name for Particulate Matrix
$   0.005="Fiber" Volume Ratio (Set Very Small Since No Continuous Fiber)
$
$ MATCRD      1COMFCOMP 0.0050  0.0000COMFCOMP 0.0000  0.0000  0.0000
$ PMEMB       0.      00.0
$ PBEND       0.
$ PTRAN       0.
$ PRINT      ALL

```

Example 3: In this input, the particulate matrix system is the same as in the previous two examples, but note in this case that for the composite material system, a continuous fiber is present. A graphite fiber (AS--) with a fiber volume ratio of 0.45 (45%) has been specified in the material card definition. The fiber properties will be read in directly from the material databank and utilized along with the computed effective properties of the particulate reinforced matrix in order to compute the overall effective properties of the composite system. Please note that for this input deck, only mechanical loads are applied to the composite, as the use and cure temperatures for each ply are set to the same value (thus eliminating thermal loads).

```

ICAN verification 3 for particulate composite
COMSAT      T
CSANB       F
BIDE        F
RINDV       F
NONUDF      T
DEFECT      F
$
$ MICRO: T=Full Analysis of Particulate Matrix Composite
$         F=No Micromechanical Calculations Performed
$
$   MICRO      T
$
$ PARTIC: T=Particulate Matrix Composite
$         F=Homogeneous Matrix Material
$
$   PARTIC     T
$
$ Material Cards for Particulate Matrix
$   PARF=Particle Code Name for Particulate Matrix
$   IMHS=Binder Code Name for Particulate Matrix
$   0.3=Particle Volume Ratio
$   0.05=Void Volume Ratio (Placeholder Only)
$
PARFIMHS    0.3    0.05
PLY         1      1   70.00   70.00   0.00   0.00  0.1
PLY         2      1   70.00   70.00   0.00   0.00  0.1
PLY         3      1   70.00   70.00   0.00   0.00  0.1
PLY         4      1   70.00   70.00   0.00   0.00  0.1
$
$ Material Cards for Particulate Matrix Composite
$   AS--=Code Name for Continuous Fiber
$   COMP=Code Name for Particulate Matrix
$   0.45=Fiber Volume Ratio (Significant Value Since Continuous Fiber)
$
MATCRD      1AS--COMP 0.4500 0.0000AS--COMP 0.0000 0.0000 0.0000
PMEMB       170.4    00.0
PBEND       0.
PTRAN       0.
PRINT      ALL

```

Example 4: For this input, the bottom ply of the composite (Ply 1) is specified to be composed of a material with continuous graphite fibers (at a 0.45 fiber volume fraction) reinforcing the particulate matrix. The remaining plies of the composite are set to be composed of the particulate matrix material only. In this manner a singly reinforced beam section can be analyzed. Please note that only mechanical loads are applied for this problem.

```

ICAN verification 4 for particulate composite
  COMSAT      T
  CSANB       F
  BIDE        F
  RINDV       F
  NONUDEF     T
  DEFECT      F
$
$ MICRO: T=Full Analysis of Particulate Matrix Composite
$         F=No Micromechanical Calculations Performed
$
$   MICRO      T
$
$ PARTIC: T=Particulate Matrix Composite
$         F=Homogeneous Matrix Material
$
$   PARTIC     T
$
$ Material Cards for Particulate Matrix:
$   PARF=Particle Code Name for Particulate Matrix
$   IMHS=Binder Code Name for Particulate Matrix
$   0.3=Particle Volume Ratio
$   0.05=Void Volume Ratio (Placeholder Only)
$
PARFIMHS      0.3    0.05
  PLY         1      2    70.00    70.00    0.00    0.00    0.1
  PLY         2      1    70.00    70.00    0.00    0.00    0.1
  PLY         3      1    70.00    70.00    0.00    0.00    0.1
  PLY         4      1    70.00    70.00    0.00    0.00    0.1
$
$ Material Cards for Particulate Matrix Composite
$   COMF=Code Name for "Fiber" With Same Properties as Particulate Matrix
$   AS---=Code Name for Continuous Graphite Fiber
$   COMP=Code Name for Particulate Matrix
$   0.005=Fiber Volume Ratio for Material With No Continuous Fiber
$   0.45=Fiber Volume Ratio for Material With Continuous Fibers
$
MATCRD        1COMFCOMP  0.0050  0.0000COMFCOMP  0.0000  0.0000  0.0000
MATCRD        2AS---COMP 0.4500  0.0000AS---COMP  0.0000  0.0000  0.0000
PMEMB         170.4      00.0
PBEND         0.
PTRAN         0.
PRINT        ALL

```

Code Compilation

A UNIX description file, or "Makefile", is available to facilitate the compiling and linking process. It can be executed by simply issuing the "make" utility command followed by a carriage return. The make utility will then execute, creating an executable version of ICAN/PART in the process. The code has been tested on a Sun Sparcstation platform running the Solaris 2.4 operating system. The code has also been compiled and tested on a IBM/PC compatible machine running the MS/DOS Version 6.2 operating system. On the PC platform, the code was compiled using Microsoft Fortran Version 5.1 and the Microsoft Fortran Powerstation (32 bit compiler).

Code Execution

The ICAN/PART code is executed in a manner typical of UNIX systems. The executable code file, input and output files should be in the same directory. Additionally, the resident material databank must be in the same directory as the ICAN/PART executable file and have the name "databk.dat". To execute the code, the following command should be issued:

```
ican < input_file > output_file
```

where ican is the executable of the ICAN/PART computer code, input_file is the name of the file with the input deck (can be any valid UNIX file name), output_file is the name of the file to which the output information should be written (again, can be any valid UNIX file name), and "<" and ">" are the UNIX input and output redirection symbols, respectively. The code execution should take place in only a few seconds in most cases.

Output Description

The printed output from ICAN/PART is very similar to that of the original ICAN, with a few exceptions accounting for the fact that a particulate matrix composite is being analyzed. Again, it is assumed that the user is familiar with the original ICAN code, and only the features of the output which differ from the original ICAN will be described.

Specific Features of Output

A.) Echo of Constituent Properties of Particulate and Binder:

Immediately after the detailed echo of the input deck, for a particulate matrix composite, the constituent properties of the particulate and binder that have been read

in from the material databank are echoed back to the user in an easy to read format. The format of the particulate matrix constituent property output is identical to that of the echo of the fiber and matrix constituent properties that is used in the original ICAN.

B.) Output of Constituent Properties of the Material System

After the echo of the constituent properties of the particulate matrix, the constituent properties and the computed effective properties for each material system are printed out. As in the original ICAN, the data for each material system is printed out sequentially. For a particulate matrix composite, the "matrix" properties that are printed out are the computed effective properties of the particulate matrix. These properties are computed from the constituent information for the particulate matrix using the equations described in reference [1].

For the "fiber" properties, the properties that are printed out depend on whether or not a continuous reinforcing fiber is present in the material system. If a continuous fiber is present, the constituent properties that have been read in from the material databank are echoed back in the output. If the material system has been specified as consisting of only a particulate reinforced matrix, the "fiber" properties are the computed effective properties of the particulate matrix, placed into the proper format (with the assumption that the "fiber" is isotropic).

After the constituent data for the material system is output, the overall effective properties for the material system are printed out. These properties are computed using the same micromechanical equations that were developed for the original ICAN [2]. The only difference for ICAN/PART is that the "matrix" properties that are used in the equations are actually the computed effective properties of the particulate reinforced matrix. For a case where the material system consists of only a particulate reinforced matrix, since the "fiber" and "matrix" properties are both set to be the computed effective properties of the particulate matrix, the computed properties of the overall material system will be equal to those of the particulate reinforced matrix system.

C.) Output of Ply Microstresses:

The output of the ply microstresses is the same as in the original ICAN. However, there are some specific issues relating to the analysis of particulate matrix composites. First, the matrix microstresses that are output are "smeared" matrix microstresses that have not been broken down into particulate or binder microstresses. For a case where no continuous fiber is present in the material system, the "A" and "B" region matrix stresses, along with the "fiber" and "matrix" stresses, are all equal since the material system is all matrix. The ICAN User's Manual [2] has a full description of how the ply microstresses are broken up into "A" and "B" regions. In the case where

continuous fibers are not present in the composite, in the terminology of the original ICAN code, the matrix stresses in the "A" region of the composite are assumed to be the "true" matrix microstresses. In the case where a continuous fiber is present in the material system, the fiber stresses are the actual stresses that are present in the fiber. The "matrix" stresses are still "smeared" stresses, but the stresses will be legitimately different in the "A" and "B" regions of the composite, and both sets of stresses must be considered.

To break down the "matrix" stresses into particle and binder microstresses, the stresses are summed up and utilized in the equations described in reference [1] as the applied stresses. The mechanical, thermal and moisture stresses are all summed together for each component direction. For example, the 1-1 "matrix" microstress due to longitudinal loading, the 1-1 stress due to transverse loading, the 1-1 stress due to thermal loading and the 1-1 stress due to moisture loading are all summed together and considered to be the overall 1-1 mechanical load in the "matrix". If no continuous fiber is present in the material system, only the "matrix" stresses in the "A" region are summed and utilized. If continuous fibers are present in the material system, the "matrix" stresses in the "A" and "B" regions are both used, but they are summed and utilized separately since the stress states in the two regions are different. The temperature and moisture gradient that are applied to the ply are also assumed to be applied to the "matrix", and are utilized in the equations described in reference [1].

D.) Output of Particulate Matrix Microstresses:

After the printout of the ply microstresses, the microstress information for the constituents of the particulate matrix is printed out for each ply. The 1-1, 2-2, 3-3, 1-2, 1-3 and 2-3 component stresses for the binder and the particle are printed out, along with the Von Mises stress for the particle and the binder. If no continuous fiber is present in the material system for any of the plies, only the "A" region stresses are printed out. If continuous fibers are present in any of the plies, both "A" and "B" region stresses are printed out. However, if for any of the plies no continuous fibers are present, the "A" and "B" region stresses are set equal for these plies.

If thermal or moisture stresses are present, the stresses due to thermal and/or moisture loading are summed into the stresses due to mechanical loading, and the stresses are printed out as one combined value. For example, what is printed out as the 1-1 stress in the binder is actually the sum of the 1-1 stress due to mechanical loading, the 1-1 stress due to thermal loading (the applied temperature gradient), and the 1-1 stress due to moisture (the applied moisture gradient).

An important point to note is that for each of the component directions, the binder material that is directly in front of the particle is assumed to have the same stress state as the particle. Also, the stresses are assumed to be constant in the particle and binder, and to be equal to the "average" stress in the region.

The stresses are printed out using a descriptive notation where, for example, SB11A is equal to the 1-1 component stress in the binder in the "A" region in the composite, SP22A is equal to the 2-2 component stress in the particle in the "A" region of the composite, and SBVMB is the Von Mises stress in the binder in the "B" region of the composite.

Sample Output

A.) Sample 1:

A sample input and relevant portions of the resulting output are shown below. In this analysis, a four ply composite consisting of particulate reinforced matrix only (i.e. no continuous fibers) is subjected to a 170.4 lb/in axial membrane load. No thermal or moisture loads are imposed. The particulate reinforced matrix consists of Particle Filler (PARF) particles in a Intermediate Modulus High Strength (IMHS) polymer epoxy binder. The output shows the echo of the constituent properties of the particulate matrix. The effective properties of the particulate matrix are printed out as the "COMP" matrix constituent properties of the overall composite material system. Since no continuous fibers are present in this material system, the "COMF" fiber properties of the composite material system are equal to those of the particulate matrix. As a result, for this case the COMF/COMP composite overall effective properties are really just those of the particulate reinforced matrix.

In the ply microstresses, the only significant stresses are the longitudinal (1-1 direction) stresses, which are equal to the applied stress. The directional stresses computed are not equivalent stresses or principal stresses, but the actual stress in the material coordinate direction. Since only axial loads were applied to a unidirectional composite, it is reasonable that the only significant stresses were the longitudinal stresses, and that the computed ply stress equals the applied stress. For the microstresses in the particulate matrix, since no continuous fiber is present in the ply material system only the "A" region stresses are printed out. Also, since no thermal loads are applied the output stresses are stresses due to mechanical loads only. The stresses for each ply are printed out, but due to the load and material configuration the stresses in each ply are equal.

ICAN verification 1 for particulate composite

COMSAT	T							
CSANB	F							
BIDE	F							
RINDV	F							
NONUDF	T							
DEFECT	F							
MICRO	T							
PARTIC	T							
PARFIMHS	0.3	0.05						
PLY	1	1	70.00	70.00	0.00	0.00	0.1	
PLY	2	1	70.00	70.00	0.00	0.00	0.1	
PLY	3	1	70.00	70.00	0.00	0.00	0.1	
PLY	4	1	70.00	70.00	0.00	0.00	0.1	
MATCRD	1	COMFCOMP	0.0050	0.0000	COMFCOMP	0.0000	0.0000	0.0000
PMEMB	170.4	00.0						
PBEND	0.							
PTRAN	0.							
PRINT	ALL							

ECHO OF CONSTITUENT PROPERTIES OF PARTICLE REINFORCED MATRIX
 PARTICLE VOLUME RATIO - 0.300 MATRIX VOLUME RATIO - 0.700
 VOID VOLUME RATIO - 0.050

1

--> CONSTITUENT PROPERTIES: ECHO FROM DATA BANK. <--

PRIMARY PARTICLE PROPERTIES;PARF PARTICLE

1	ELASTIC MODULI	EFP1	0.1000E+06
2		EFP2	0.1000E+06
3	SHEAR MODULI	GFP12	0.4170E+05
4		GFP23	0.4170E+05
5	POISSON"S RATIO	NUFP12	0.2000E+00
6		NUFP23	0.2000E+00
7	THERM. EXP. COEF.	CTEFP1	0.3600E-05
8		CTEFP2	0.3600E-05
9	DENSITY	RHOFP	0.8830E-01
10	NO. OF FIBERS/END	NFP	0.1000E+05
11	FIBER DIAMETER	DIFP	0.3000E-03
12	HEAT CAPACITY	CFPC	0.1700E+00
13	HEAT CONDUCTIVITY	KFP1	0.8680E+00
14		KFP2	0.8680E+00
15		KFP3	0.8680E+00
16	STRENGTHS	SFPT	0.2800E+06
17		SFPC	0.2000E+06

PRIMARY MATRIX PROPERTIES;IMHS MATRIX. DRY RT. PROPERTIES.

1	ELASTIC MODULUS	EMP	0.5000E+06
2	SHEAR MODULUS	GMP	0.1852E+06
3	POISSON"S RATIO	NUMP	0.3500E+00
4	THERM. EXP. COEF.	CTEMP	0.3600E-04
5	DENSITY	RHOMP	0.4400E-01
6	HEAT CAPACITY	CMPC	0.2500E+00
7	HEAT CONDUCTIVITY	KMP	0.8681E-02
8	STRENGTHS	SMPT	0.1500E+05
9		SMPC	0.3500E+05
10		SMPS	0.1300E+05
11	MOISTURE COEF	BTAMP	0.4000E-02
12	DIFFUSIVITY	DIFMP	0.2000E-03

BASED ON MICROMECHANICS OF PARTICULATE R/F COMPOSITES: ELASTIC AND THERMAL PROPERTIES.

1

--> CONSTITUENT PROPERTIES: ECHO FROM DATA BANK. <--

PRIMARY FIBER PROPERTIES;COMF FIBER

1	ELASTIC MODULI	EF11	0.3368E+06
2		EF22	0.3368E+06
3	SHEAR MODULI	GF12	0.1273E+06
4		GF23	0.1273E+06
5	POISSON"S RATIO	NUF12	0.3229E+00
6		NUF23	0.3229E+00
7	THERM. EXP. COEF.	CTEF11	0.3208E-04
8		CTEF22	0.3208E-04
9	DENSITY	RHOF1	0.5729E-01
10	NO. OF FIBERS/END	NFP	0.1000E+05
11	FIBER DIAMETER	DIF1	0.3000E-03
12	HEAT CAPACITY	CF11	0.2130E+00
13	HEAT CONDUCTIVITY	KF11	0.1633E-01
14		KF22	0.1633E-01
15		KF33	0.1633E-01
16	STRENGTHS	SF11	0.1000E+03
17		SF22	0.1000E+03

PRIMARY MATRIX PROPERTIES;COMP MATRIX. DRY RT. PROPERTIES.

1	ELASTIC MODULUS	EMP	0.3368E+06	*	NEW
2	SHEAR MODULUS	GMP	0.1273E+06	*	NEW
3	POISSON"S RATIO	NUMP	0.3229E+00	*	NEW
4	THERM. EXP. COEF.	CTEMP	0.3208E-04	*	NEW
5	DENSITY	RHOMP	0.5729E-01	*	NEW
6	HEAT CAPACITY	CMPC	0.2130E+00	*	NEW
7	HEAT CONDUCTIVITY	KMP	0.1633E-01	*	NEW
8	STRENGTHS	SMPT	0.1000E+03	*	NEW
9		SMPC	0.1000E+03	*	NEW
10		SMPS	0.1000E+03	*	NEW

11	MOISTURE COEF	BTAMP	0.4000E-02	*	NEW
12	DIFFUSIVITY	DIFMP	0.2000E-03	*	NEW

1

PRIMARY COMPOSITE PROPERTIES;COMF/COMP

BASED ON MICROMECHANICS OF INTRAPLY HYBRID COMPOSITES: ELASTIC AND THERMAL PROPERTIES.

FIBER VOLUME RATIO - 0.005 MATRIX VOLUME RATIO - 0.995
VOID VOLUME RATIO - 0.000

1	ELASTIC MODULI	EPC1	0.3368E+06
2		EPC2	0.3368E+06
3		EPC3	0.3368E+06
4	SHEAR MODULI	GPC12	0.1273E+06
5		GPC23	0.1273E+06
6		GPC13	0.1273E+06
7	POISSON"S RATIO	NUPC12	0.3229E+00
8		NUPC23	0.3229E+00
9		NUPC13	0.3229E+00
10	THERM. EXP. COEF.	CTEPC1	0.3208E-04
11		CTEPC2	0.3208E-04
12		CTEPC3	0.3208E-04
13	DENSITY	RHOPC	0.5729E-01
14	HEAT CAPACITY	CPC	0.2130E+00
15	HEAT CONDUCTIVITY	KPC1	0.1633E-01
16		KPC2	0.1633E-01
17		KPC3	0.1633E-01
18	STRENGTHS	SPC1T	0.5000E+00
19		SPC1C	0.5000E+00
20		SPC2T	0.1000E+03
21		SPC2C	0.1000E+03
22		SPC12	0.1000E+03
23	MOIST. DIFFUSIVITY	DPC1	0.1990E-03
24		DPC2	0.1859E-03
25		DPC3	0.1859E-03
26	MOIST. EXP. COEF.	BTAPC1	0.3980E-02
27		BTAPC2	0.3723E-02
28		BTAPC3	0.3723E-02
29	FLEXURAL MODULI	EPC1F	0.3368E+06
30		EPC2F	0.3368E+06
31	STRENGTHS	SPC23	0.1000E+03
32		SPC1F	0.6250E+00
33		SPC2F	0.1250E+03
34		SPCSB	0.1500E+03
35	PLY THICKNESS	TPC	0.5000E-02
36	INTERPLY THICKNESS	PLPC	0.3460E-02
37	INTERFIBER SPACING	PLPCS	0.3460E-02

M I C R O S T R E S S E S

FOR LOAD CONDITIONS

MEMBRANE LOADS NBS (X, Y, XY-M) ARE 170. 0. 0.
 BENDING LOADS MBS (X, Y, XY-M) ARE 0. 0. 0.
 QXZ, QYZ AND APPLIED PRESSURES ARE 0. 0. 0. 0.
 NOTE : NO MOISTURE OR TEMPERATURE

(NOTE: ROWS-PROPERTY, COLUMNS-LAYER)

PLY NUMBER		1	2	3	4
MATERIAL SYSTEM		COMF/COMP	COMF/COMP	COMF/COMP	COMF/COMP
ORIENTATION		/	/	/	/
		0.0	0.0	0.0	0.0
1	SM1L	0.4260E+03	0.4260E+03	0.4260E+03	0.4260E+03
1	SM1L	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	SM1T	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	SM1T	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
3	SF1L	0.4260E+03	0.4260E+03	0.4260E+03	0.4260E+03
3	SF1L	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
4	SF1T	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
4	SF1T	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
5	SM2AL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
5	SM2AL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
6	SM2AT	0.1526E-04	0.1526E-04	0.1526E-04	0.1526E-04
6	SM2AT	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
7	SM2BL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
7	SM2BL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
8	SM2BT	0.1526E-04	0.1526E-04	0.1526E-04	0.1526E-04
8	SM2BT	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
9	SF2BL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
9	SF2BL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
10	SF2BT	0.1526E-04	0.1526E-04	0.1526E-04	0.1526E-04
10	SF2BT	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
11	SM3AL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
11	SM3AL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
12	SM3AT	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
12	SM3AT	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
13	SM3BL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
13	SM3BL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
14	SM3BT	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
14	SM3BT	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
15	SF3BL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
15	SF3BL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
16	SF3BT	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
16	SF3BT	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
17	SM12A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
17	SM12A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
18	SM12B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
18	SM12B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
19	SF12B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
19	SF12B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
20	SM13A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
20	SM13A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
21	SM13B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
21	SM13B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

22	SF13B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
22	SF13B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
23	SM23A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
23	SM23A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
24	SM23B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
24	SM23B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
25	SF23B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
25	SF23B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
42	SI22B	0.1526E-04	0.1526E-04	0.1526E-04	0.1526E-04
42	SI22B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
43	SI33B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
43	SI33B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
44	SI12B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
44	SI12B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
45	SINC	0.1526E-04	0.1526E-04	0.1526E-04	0.1526E-04
45	SINC	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
46	SISC	-0.1526E-04	-0.1526E-04	-0.1526E-04	-0.1526E-04
46	SISC	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

NOTATION: S --- STRESS (SIGMA)
 M --- MATRIX , F --- FIBER AND I --- INTERFACE
 1,2,3 --- DIRECTIONS FOR STRESSES - PLY MATERIAL AXES
 L,T --- DIRECTIONS OF PLY STRESSES
 A --- REGION CONTAINING NO FIBERS
 B --- REGION CONTAINING FIBERS AND MATRIX
 EXAMPLE: SM2AL STANDS FOR TRANSVERSE NORMAL STRESS
 IN REGION A DUE TO A LOAD IN THE LONGITUDINAL
 DIRECTION

P A R T I C U L A T E M A T R I X M I C R O S T R E S S E S

OVERALL MATRIX STRESS IN EACH PLY IS THE SUM OF THE
MECHANICAL, THERMAL AND MOISTURE STRESSES
COMPUTED ABOVE

NOTE: NO THERMAL OR MOISTURE STRESSES ARE PRESENT
IF PRESENT, THERMAL AND MOISTURE STRESSES ARE
SUMMED INTO 11, 22, AND 33 STRESS COMPONENTS

(NOTE: ROWS-PROPERTY, COLUMNS-LAYER)

PLY NUMBER		1	2	3	4
1	SB11A	0.6323E+03	0.6323E+03	0.6323E+03	0.6323E+03
3	SB22A	0.1714E+02	0.1714E+02	0.1714E+02	0.1714E+02
5	SB33A	0.1714E+02	0.1714E+02	0.1714E+02	0.1714E+02
7	SB12A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
9	SB13A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
11	SB23A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
13	SBVMA	0.6152E+03	0.6152E+03	0.6152E+03	0.6152E+03
15	SP11A	0.1719E+03	0.1719E+03	0.1719E+03	0.1719E+03
17	SP22A	-0.1260E+02	-0.1260E+02	-0.1260E+02	-0.1260E+02
19	SP33A	-0.1260E+02	-0.1260E+02	-0.1260E+02	-0.1260E+02
21	SP12A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
23	SP13A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
25	SP23A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
27	SPVMA	0.1845E+03	0.1845E+03	0.1845E+03	0.1845E+03

NOTATION: S --- STRESS (SIGMA)
B--BINDER, P--- PARTICLE
VM --- VON MISES STRESS

IF PARTICULATE COMPOSITE HAS SIGNIFICANT CONTINUOUS
FIBER, STRESSES ARE BROKEN UP INTO A AND B REGIONS
FROM ABOVE. IF SIGNIFICANT CONTINUOUS FIBER IS
NOT PRESENT, A AND B REGION STRESSES ARE EQUAL

STRESSES IN BINDER REGIONS IN FRONT OF PARTICLE
ARE ASSUMED TO BE EQUAL TO THE PARTICLE STRESSES

1,2,3 --- STRESS DIRECTIONS - PLY MATERIAL AXES
L,T --- STRESS DIRECTIONS - PARTICULATE MATRIX
A --- MATRIX REGION WITH NO CONTINUOUS FIBERS
B --- MATRIX REGION WITH CONTINUOUS FIBERS

EXAMPLE: SB22B STANDS FOR TRANSVERSE NORMAL
STRESS IN BINDER OF PARTICULATE MATRIX
IN REGION B OF THE COMPOSITE

B.) Sample 2:

The sample input and relevant portions of the resulting output are shown below. This analysis is similar to the previous example, except that continuous graphite fibers (at 45% volume fraction) are present in the material system along with the particulate reinforced matrix. For this example, the effective properties of the particulate matrix are again computed and printed out as the properties of the "COMP" matrix constituent of the material system. Unlike the previous example, since in this case continuous reinforcing fibers are present in the overall material system, the actual fiber properties are echoed back from the databank in the ply material system definition. The effective properties for the AS--/COMP material system are the actual effective properties obtained by combining the AS-- fiber with the particulate reinforced matrix.

Due to the presence of continuous reinforcing fibers in the material system, distinct fiber and "matrix" constituent stresses are present in the ply microstresses. The transverse "matrix" stresses in the "A" and "B" regions also differ from each other due the presence of the continuous fibers. In the particulate matrix microstresses, since the "smeared" matrix stresses are different in the "A" and "B" regions of the overall composite, the microstresses in the particle and binder need to be computed for both regions of the overall composite. Note that since no thermal or moisture stresses were applied to the composite, the output stresses are due to mechanical loads only.

ICAN verification 3 for particulate composite

COMSAT	T							
CSANB	F							
BIDE	F							
RINDV	F							
NONUDF	T							
DEFECT	F							
MICRO	T							
PARTIC	T							
PARFIMHS	0.3	0.05						
PLY	1	1	70.00	70.00	0.00	0.00	0.1	
PLY	2	1	70.00	70.00	0.00	0.00	0.1	
PLY	3	1	70.00	70.00	0.00	0.00	0.1	
PLY	4	1	70.00	70.00	0.00	0.00	0.1	
MATCRD	1AS--COMP	0.4500	0.0000AS--COMP	0.0000	0.0000	0.0000	0.0000	
PMEMB	170.4	00.0						
PBEND	0.							
PTRAN	0.							
PRINT	ALL							

ECHO OF CONSTITUENT PROPERTIES OF PARTICLE REINFORCED MATRIX
 PARTICLE VOLUME RATIO - 0.300 MATRIX VOLUME RATIO - 0.700
 VOID VOLUME RATIO - 0.050
 1

--> CONSTITUENT PROPERTIES: ECHO FROM DATA BANK. <--

PRIMARY PARTICLE PROPERTIES;PARF PARTICLE

1	ELASTIC MODULI	EF1	0.1000E+06
2		EF2	0.1000E+06
3	SHEAR MODULI	GFP12	0.4170E+05
4		GFP23	0.4170E+05
5	POISSON"S RATIO	NUFP12	0.2000E+00
6		NUFP23	0.2000E+00
7	THERM. EXP. COEF.	CTEFP1	0.3600E-05
8		CTEFP2	0.3600E-05
9	DENSITY	RHOF	0.8830E-01
10	NO. OF FIBERS/END	NFP	0.1000E+05
11	FIBER DIAMETER	DIFP	0.3000E-03
12	HEAT CAPACITY	CFPC	0.1700E+00
13	HEAT CONDUCTIVITY	KFP1	0.8680E+00
14		KFP2	0.8680E+00
15		KFP3	0.8680E+00
16	STRENGTHS	SFPT	0.2800E+06
17		SFPC	0.2000E+06

PRIMARY MATRIX PROPERTIES;IMHS MATRIX. DRY RT. PROPERTIES.

1	ELASTIC MODULUS	EMP	0.5000E+06
2	SHEAR MODULUS	GMP	0.1852E+06
3	POISSON"S RATIO	NUMP	0.3500E+00
4	THERM. EXP. COEF.	CTEMP	0.3600E-04
5	DENSITY	RHOMP	0.4400E-01
6	HEAT CAPACITY	CMPC	0.2500E+00
7	HEAT CONDUCTIVITY	KMP	0.8681E-02
8	STRENGTHS	SMPT	0.1500E+05
9		SMPC	0.3500E+05

10		SMPS	0.1300E+05
11	MOISTURE COEF	BTAMP	0.4000E-02
12	DIFFUSIVITY	DIFMP	0.2000E-03

BASED ON MICROMECHANICS OF PARTICULATE R/F COMPOSITES: ELASTIC AND THERMAL PROPERTIES.

1

--> CONSTITUENT PROPERTIES: ECHO FROM DATA BANK. <--

PRIMARY FIBER PROPERTIES;AS-- FIBER

1	ELASTIC MODULI	EFF1	0.3100E+08
2		EFF2	0.2000E+07
3	SHEAR MODULI	GFP12	0.2000E+07
4		GFP23	0.1000E+07
5	POISSON"S RATIO	NUFP12	0.2000E+00
6		NUFP23	0.2500E+00
7	THERM. EXP. COEF.	CTEFP1	-0.5500E-06
8		CTEFP2	0.5600E-05
9	DENSITY	RHOFP	0.6300E-01
10	NO. OF FIBERS/END	NFP	0.1000E+05
11	FIBER DIAMETER	DIFP	0.3000E-03
12	HEAT CAPACITY	CFPC	0.1700E+00
13	HEAT CONDUCTIVITY	KFP1	0.4030E+01
14		KFP2	0.4030E+00
15		KFP3	0.4030E+00
16	STRENGTHS	SFPT	0.4000E+06
17		SFPC	0.4000E+06

PRIMARY MATRIX PROPERTIES;COMP MATRIX. DRY RT. PROPERTIES.

1	ELASTIC MODULUS	EMP	0.3368E+06	*	NEW
2	SHEAR MODULUS	GMP	0.1273E+06	*	NEW
3	POISSON"S RATIO	NUMP	0.3229E+00	*	NEW
4	THERM. EXP. COEF.	CTEMP	0.3208E-04	*	NEW
5	DENSITY	RHOMP	0.5729E-01	*	NEW
6	HEAT CAPACITY	CMPC	0.2130E+00	*	NEW
7	HEAT CONDUCTIVITY	KMP	0.1633E-01	*	NEW
8	STRENGTHS	SMPT	0.1000E+03	*	NEW
9		SMPC	0.1000E+03	*	NEW
10		SMPS	0.1000E+03	*	NEW
11	MOISTURE COEF	BTAMP	0.4000E-02	*	NEW
12	DIFFUSIVITY	DIFMP	0.2000E-03	*	NEW

1

PRIMARY COMPOSITE PROPERTIES;AS---/COMP

BASED ON MICROMECHANICS OF INTRAPLY HYBRID COMPOSITES: ELASTIC AND THERMAL PROPERTIES.

FIBER VOLUME RATIO - 0.450 MATRIX VOLUME RATIO - 0.550 VOID
VOLUME RATIO - 0.000

1	ELASTIC MODULI	EPC1	0.1414E+08
2		EPC2	0.7618E+06
3		EPC3	0.7618E+06
4	SHEAR MODULI	GPC12	0.3423E+06
5		GPC23	0.2096E+06
6		GPC13	0.3423E+06
7	POISSON"S RATIO	NUPC12	0.2676E+00
8		NUPC23	0.4597E+00
9		NUPC13	0.2676E+00
10	THERM. EXP. COEF.	CTEPC1	-0.1224E-06
11		CTEPC2	0.2029E-04
12		CTEPC3	0.2029E-04
13	DENSITY	RHOPC	0.5986E-01
14	HEAT CAPACITY	CPC	0.1926E+00
15	HEAT CONDUCTIVITY	KPC1	0.1822E+01
16		KPC2	0.3611E-01
17		KPC3	0.3611E-01
18	STRENGTHS	SPC1T	0.1800E+06
19		SPC1C	0.1043E+04
20		SPC2T	0.8164E+02
21		SPC2C	0.8164E+02
22		SPC12	0.7932E+02
23	MOIST. DIFFUSIVITY	DPC1	0.1100E-03
24		DPC2	0.6584E-04
25		DPC3	0.6584E-04
26	MOIST. EXP. COEF.	BTAPC1	0.5243E-04
27		BTAPC2	0.1736E-02
28		BTAPC3	0.1736E-02
29	FLEXURAL MODULI	EPC1F	0.1414E+08
30		EPC2F	0.7618E+06
31	STRENGTHS	SPC23	0.6827E+02
32		SPC1F	0.2593E+04
33		SPC2F	0.1020E+03
34		SPCSB	0.1190E+03
35	PLY THICKNESS	TPC	0.5000E-02
36	INTERPLY THICKNESS	PLPC	0.9633E-04
37	INTERFIBER SPACING	PLPCS	0.9633E-04

M I C R O S T R E S S E S

FOR LOAD CONDITIONS

MEMBRANE LOADS NBS (X, Y, XY-M) ARE 170. 0. 0.
 BENDING LOADS MBS (X, Y, XY-M) ARE 0. 0. 0.
 QXZ, QYZ AND APPLIED PRESSURES ARE 0. 0. 0. 0.

NOTE : NO MOISTURE OR TEMPERATURE

(NOTE: ROWS-PROPERTY, COLUMNS-LAYER)

PLY NUMBER		1	2	3	4
MATERIAL SYSTEM		AS--/COMP	AS--/COMP	AS--/COMP	AS--/COMP
ORIENTATION		/	/	/	/
		0.0	0.0	0.0	0.0
1	SM1L	0.1015E+02	0.1015E+02	0.1015E+02	0.1015E+02
1	SM1L	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	SM1T	-0.3505E-08	-0.3505E-08	-0.3505E-08	0.0000E+00
2	SM1T	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
3	SF1L	0.9343E+03	0.9343E+03	0.9343E+03	0.9343E+03
3	SF1L	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
4	SF1T	0.1588E-08	0.1588E-08	0.1588E-08	0.0000E+00
4	SF1T	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
5	SM2AL	0.5614E+00	0.5614E+00	0.5614E+00	0.5614E+00
5	SM2AL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
6	SM2AT	-0.2583E-06	-0.2583E-06	-0.2583E-06	0.0000E+00
6	SM2AT	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
7	SM2BL	-0.2755E+00	-0.2755E+00	-0.2755E+00	-0.2755E+00
7	SM2BL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
8	SM2BT	-0.5841E-06	-0.5841E-06	-0.5841E-06	0.0000E+00
8	SM2BT	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
9	SF2BL	-0.2755E+00	-0.2755E+00	-0.2755E+00	-0.2755E+00
9	SF2BL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
10	SF2BT	-0.5841E-06	-0.5841E-06	-0.5841E-06	0.0000E+00
10	SF2BT	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
11	SM3AL	0.5614E+00	0.5614E+00	0.5614E+00	0.5614E+00
11	SM3AL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
12	SM3AT	0.2885E-07	0.2885E-07	0.2885E-07	0.0000E+00
12	SM3AT	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
13	SM3BL	-0.2755E+00	-0.2755E+00	-0.2755E+00	-0.2755E+00
13	SM3BL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
14	SM3BT	-0.1416E-07	-0.1416E-07	-0.1416E-07	0.0000E+00
14	SM3BT	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
15	SF3BL	-0.2755E+00	-0.2755E+00	-0.2755E+00	-0.2755E+00
15	SF3BL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
16	SF3BT	-0.1416E-07	-0.1416E-07	-0.1416E-07	0.0000E+00
16	SF3BT	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
17	SM12A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
17	SM12A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
18	SM12B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
18	SM12B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
19	SF12B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
19	SF12B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
20	SM13A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
20	SM13A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
21	SM13B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
21	SM13B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

22	SF13B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
22	SF13B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
23	SM23A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
23	SM23A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
24	SM23B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
24	SM23B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
25	SF23B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
25	SF23B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
42	SI22B	-0.2755E+00	-0.2755E+00	-0.2755E+00	-0.2755E+00
42	SI22B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
43	SI33B	-0.2755E+00	-0.2755E+00	-0.2755E+00	-0.2755E+00
43	SI33B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
44	SI12B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
44	SI12B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
45	SINC	0.2859E+00	0.2859E+00	0.2859E+00	0.2859E+00
45	SINC	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
46	SISC	0.4321E-06	0.4321E-06	0.4321E-06	0.0000E+00
46	SISC	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

NOTATION: S --- STRESS (SIGMA)
 M --- MATRIX , F --- FIBER AND I --- INTERFACE
 1,2,3 --- DIRECTIONS FOR STRESSES - PLY MATERIAL AXES
 L,T --- DIRECTIONS OF PLY STRESSES
 A --- REGION CONTAINING NO FIBERS
 B --- REGION CONTAINING FIBERS AND MATRIX
 EXAMPLE: SM2AL STANDS FOR TRANSVERSE NORMAL STRESS
 IN REGION A DUE TO A LOAD IN THE LONGITUDINAL
 DIRECTION

P A R T I C U L A T E M A T R I X M I C R O S T R E S S E S

OVERALL MATRIX STRESS IN EACH PLY IS THE SUM OF THE
MECHANICAL, THERMAL AND MOISTURE STRESSES
COMPUTED ABOVE

NOTE: NO THERMAL OR MOISTURE STRESSES ARE PRESENT
IF PRESENT, THERMAL AND MOISTURE STRESSES ARE
SUMMED INTO 11, 22, AND 33 STRESS COMPONENTS

(NOTE: ROWS-PROPERTY, COLUMNS-LAYER)

PLY NUMBER		1	2	3	4
1	SB11A	0.1511E+02	0.1511E+02	0.1511E+02	0.1511E+02
2	SB11B	0.1505E+02	0.1505E+02	0.1505E+02	0.1505E+02
3	SB22A	0.1264E+01	0.1264E+01	0.1264E+01	0.1264E+01
4	SB22B	-0.1145E-01	-0.1145E-01	-0.1145E-01	-0.1145E-01
5	SB33A	0.1264E+01	0.1264E+01	0.1264E+01	0.1264E+01
6	SB33B	-0.1145E-01	-0.1145E-01	-0.1145E-01	-0.1145E-01
7	SB12A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
8	SB12B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
9	SB13A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
10	SB13B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
11	SB23A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
12	SB23B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
13	SBVMA	0.1385E+02	0.1385E+02	0.1385E+02	0.1385E+02
14	SBVMB	0.1506E+02	0.1506E+02	0.1506E+02	0.1506E+02
15	SP11A	0.4064E+01	0.4064E+01	0.4064E+01	0.4064E+01
16	SP11B	0.4113E+01	0.4113E+01	0.4113E+01	0.4113E+01
17	SP22A	-0.9039E-01	-0.9039E-01	-0.9039E-01	-0.9039E-01
18	SP22B	-0.4034E+00	-0.4034E+00	-0.4034E+00	-0.4034E+00
19	SP33A	-0.9039E-01	-0.9039E-01	-0.9039E-01	-0.9039E-01
20	SP33B	-0.4034E+00	-0.4034E+00	-0.4034E+00	-0.4034E+00
21	SP12A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
22	SP12B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
23	SP13A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
24	SP13B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
25	SP23A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
26	SP23B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
27	SPVMA	0.4154E+01	0.4154E+01	0.4154E+01	0.4154E+01
28	SPVMB	0.4517E+01	0.4517E+01	0.4517E+01	0.4517E+01

NOTATION: S --- STRESS (SIGMA)
B---BINDER, P--- PARTICLE
VM --- VON MISES STRESS

IF PARTICULATE COMPOSITE HAS SIGNIFICANT CONTINUOUS
FIBER, STRESSES ARE BROKEN UP INTO A AND B REGIONS
FROM ABOVE. IF SIGNIFICANT CONTINUOUS FIBER IS
NOT PRESENT, A AND B REGION STRESSES ARE EQUAL

STRESSES IN BINDER REGIONS IN FRONT OF PARTICLE
ARE ASSUMED TO BE EQUAL TO THE PARTICLE STRESSES

1,2,3 --- STRESS DIRECTIONS - PLY MATERIAL AXES

L,T --- STRESS DIRECTIONS - PARTICULATE MATRIX
A --- MATRIX REGION WITH NO CONTINUOUS FIBERS
B --- MATRIX REGION WITH CONTINUOUS FIBERS

EXAMPLE: SB22B STANDS FOR TRANSVERSE NORMAL
STRESS IN BINDER OF PARTICULATE MATRIX
IN REGION B OF THE COMPOSITE

C.) Sample 3

A sample input and the relevant portions of the resulting output are shown below. This analysis is similar to Sample 1, except that the use and cure temperatures are set to 170 degrees F instead of 70 degrees F. The purpose of this change is to illustrate the degradation in binder properties that takes place due to elevated temperature. The effects of the degradation of the binder due to temperature result in degradation of the overall particulate reinforced matrix properties, as can be seen by comparing the "COMP" computed properties in this example to those shown in Sample 1. The effects of the binder property degradation can also be seen in the particulate matrix microstresses. For example, the binder stress in the 1-1 direction is lower for this case than in Sample 1, while the particle stress in the 1-1 direction is higher in this case. This change in the stress state results from the binder having a lower stiffness than in the previous case due to the degradation due to temperature.

ICAN verification 5 for particulate composite

COMSAT	T							
CSANB	F							
BIDE	F							
RINDV	F							
NONUDF	T							
DEFECT	F							
MICRO	T							
PARTIC	T							
PARFIMHS	0.3	0.05						
PLY	1	1	170.00	170.00	0.00	0.00	0.1	
PLY	2	1	170.00	170.00	0.00	0.00	0.1	
PLY	3	1	170.00	170.00	0.00	0.00	0.1	
PLY	4	1	170.00	170.00	0.00	0.00	0.1	
MATCHRD	1	COMFCOMP	0.0050	0.0000	COMFCOMP	0.0000	0.0000	0.0000
PMEMB	170.4	00.0						
PBEND	0.							
PTRAN	0.							
PRINT	ALL							

ECHO OF CONSTITUENT PROPERTIES OF PARTICLE REINFORCED MATRIX
 PARTICLE VOLUME RATIO - 0.300 MATRIX VOLUME RATIO - 0.700 VOID VOLUME RATIO -
 0.050
 1

--> CONSTITUENT PROPERTIES: ECHO FROM DATA BANK. <--

PRIMARY PARTICLE PROPERTIES;PARF PARTICLE

1	ELASTIC MODULI	EFP1	0.1000E+06
2		EFP2	0.1000E+06
3	SHEAR MODULI	GFP12	0.4170E+05
4		GFP23	0.4170E+05
5	POISSON'S RATIO	NUFP12	0.2000E+00
6		NUFP23	0.2000E+00
7	THERM. EXP. COEF.	CTEFP1	0.3600E-05
8		CTEFP2	0.3600E-05
9	DENSITY	RHOF1	0.8830E-01
10	NO. OF FIBERS/END	NFP	0.1000E+05
11	FIBER DIAMETER	DIFP	0.3000E-03
12	HEAT CAPACITY	CFPC	0.1700E+00
13	HEAT CONDUCTIVITY	KFP1	0.8680E+00
14		KFP2	0.8680E+00
15		KFP3	0.8680E+00
16	STRENGTHS	SFPT	0.2800E+06
17		SFPC	0.2000E+06

PRIMARY MATRIX PROPERTIES;IMHS MATRIX. DRY RT. PROPERTIES.

REFERENCE TEMP. -	70.00	DRY GLASS TRANS. TEMP. -	420.00
TEST TEMP. -	170.00	PCT. MOISTURE -	0.000

ORIGINAL MATRIX PROPERTIES

1	ELASTIC MODULUS	EMP	0.5000E+06
2	SHEAR MODULUS	GMP	0.1852E+06
3	POISSON'S RATIO	NUMP	0.3500E+00
4	THERM. EXP. COEF.	CTEMP	0.3600E-04
5	DENSITY	RHOMP	0.4400E-01
6	HEAT CAPACITY	CMPC	0.2500E+00
7	HEAT CONDUCTIVITY	KMP	0.8681E-02
8	STRENGTHS	SMPT	0.1500E+05
9		SMPC	0.3500E+05
10		SMPS	0.1300E+05
11	MOISTURE COEF	BTAMP	0.4000E-02
12	DIFFUSIVITY	DIFMP	0.2000E-03

NEW PROPERTIES: CHANGED BECAUSE
OF TEMPERATURE/MOISTURE EFFECTS

*	NEW EMP	0.4226E+06
*	NEW GMP	0.1565E+06
*	NEW NUMP	0.3500E+00
*	NEW CTEMP	0.4260E-04
*	NEW RHOMP	0.4400E-01
*	NEW CMPC	0.2958E+00
*	NEW KMP	0.1027E-01
*	NEW SMPT	0.1268E+05
*	NEW SMPC	0.2958E+05
*	NEW SMPS	0.1099E+05
*	NEW BTAMP	0.4000E-02
*	NEW DIFMP	0.2000E-03

BASED ON MICROMECHANICS OF PARTICULATE R/F COMPOSITES: ELASTIC AND THERMAL PROPERTIES.

1

--> CONSTITUENT PROPERTIES: ECHO FROM DATA BANK. <--

PRIMARY FIBER PROPERTIES;COMP FIBER

1	ELASTIC MODULI	EFPP1	0.2931E+06
2		EFPP2	0.2931E+06
3	SHEAR MODULI	GFP12	0.1110E+06
4		GFP23	0.1110E+06
5	POISSON'S RATIO	NUFP12	0.3200E+00
6		NUFP23	0.3200E+00
7	THERM. EXP. COEF.	CTEFP1	0.3726E-04
8		CTEFP2	0.3726E-04
9	DENSITY	RHOF	0.5729E-01
10	NO. OF FIBERS/END	NFP	0.1000E+05
11	FIBER DIAMETER	DIFP	0.3000E-03
12	HEAT CAPACITY	CFPC	0.2376E+00
13	HEAT CONDUCTIVITY	KFP1	0.1927E-01
14		KFP2	0.1927E-01
15		KFP3	0.1927E-01
16	STRENGTHS	SFPT	0.1000E+03
17		SFPC	0.1000E+03

PRIMARY MATRIX PROPERTIES;COMP MATRIX. DRY RT. PROPERTIES.

1	ELASTIC MODULUS	EMP	0.2931E+06	*	NEW
2	SHEAR MODULUS	GMP	0.1110E+06	*	NEW
3	POISSON'S RATIO	NUMP	0.3200E+00	*	NEW
4	THERM. EXP. COEF.	CTEMP	0.3726E-04	*	NEW
5	DENSITY	RHOMP	0.5729E-01	*	NEW
6	HEAT CAPACITY	CMPC	0.2376E+00	*	NEW
7	HEAT CONDUCTIVITY	KMP	0.1927E-01	*	NEW
8	STRENGTHS	SMPT	0.1000E+03	*	NEW
9		SMPC	0.1000E+03	*	NEW
10		SMPS	0.1000E+03	*	NEW
11	MOISTURE COEF	BTAMP	0.4000E-02	*	NEW
12	DIFFUSIVITY	DIFMP	0.2000E-03	*	NEW

1

PRIMARY COMPOSITE PROPERTIES;COMF/COMP

BASED ON MICROMECHANICS OF INTRAPLY HYBRID COMPOSITES: ELASTIC AND THERMAL PROPERTIES.

FIBER VOLUME RATIO - 0.005		MATRIX VOLUME RATIO - 0.995		VOID VOLUME RATIO -
0.000				
1	ELASTIC MODULI	EPC1	0.2931E+06	
2		EPC2	0.2931E+06	
3		EPC3	0.2931E+06	
4	SHEAR MODULI	GPC12	0.1110E+06	
5		GPC23	0.1110E+06	
6		GPC13	0.1110E+06	
7	POISSON'S RATIO	NUPC12	0.3200E+00	
8		NUPC23	0.3200E+00	
9		NUPC13	0.3200E+00	
10	THERM. EXP. COEF.	CTEPC1	0.3726E-04	
11		CTEPC2	0.3726E-04	
12		CTEPC3	0.3726E-04	
13	DENSITY	RHOPC	0.5729E-01	
14	HEAT CAPACITY	CPC	0.2376E+00	
15	HEAT CONDUCTIVITY	KPC1	0.1927E-01	
16		KPC2	0.1927E-01	
17		KPC3	0.1927E-01	
18	STRENGTHS	SPC1T	0.5000E+00	
19		SPC1C	0.5000E+00	
20		SPC2T	0.1000E+03	
21		SPC2C	0.1000E+03	
22		SPC12	0.1000E+03	
23	MOIST. DIFFUSIVITY	DPC1	0.1990E-03	
24		DPC2	0.1859E-03	
25		DPC3	0.1859E-03	
26	MOIST. EXP. COEF.	BTAPC1	0.3980E-02	
27		BTAPC2	0.3723E-02	
28		BTAPC3	0.3723E-02	
29	FLEXURAL MODULI	EPC1F	0.2931E+06	
30		EPC2F	0.2931E+06	
31	STRENGTHS	SPC23	0.1000E+03	
32		SPC1F	0.6250E+00	
33		SPC2F	0.1250E+03	
34		SPCSB	0.1500E+03	
35	PLY THICKNESS	TPC	0.5000E-02	
36	INTERPLY THICKNESS	PLPC	0.3460E-02	
37	INTERFIBER SPACING	PLPCS	0.3460E-02	

M I C R O S T R E S S E S

FOR LOAD CONDITIONS

MEMBRANE LOADS NBS(X,Y,XY-M) ARE 170. 0. 0.
 BENDING LOADS MBS(X,Y,XY-M) ARE 0. 0. 0.
 QXZ,QYZ AND APPLIED PRESSURES ARE 0. 0. 0. 0.
 NOTE : NO MOISTURE OR TEMPERATURE

(NOTE: ROWS-PROPERTY, COLUMNS-LAYER)

PLY NUMBER		1	2	3	4
MATERIAL SYSTEM		COMF/COMP	COMF/COMP	COMF/COMP	COMF/COMP
ORIENTATION		0.0	0.0	0.0	0.0
1	SM1L	0.4260E+03	0.4260E+03	0.4260E+03	0.4260E+03
1	SM1L	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	SM1T	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	SM1T	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
3	SF1L	0.4260E+03	0.4260E+03	0.4260E+03	0.4260E+03
3	SF1L	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
4	SF1T	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
4	SF1T	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
5	SM2AL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
5	SM2AL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
6	SM2AT	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
6	SM2AT	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
7	SM2BL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
7	SM2BL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
8	SM2BT	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
8	SM2BT	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
9	SF2BL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
9	SF2BL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
10	SF2BT	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
10	SF2BT	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
11	SM3AL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
11	SM3AL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
12	SM3AT	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
12	SM3AT	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
13	SM3BL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
13	SM3BL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
14	SM3BT	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
14	SM3BT	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
15	SF3BL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
15	SF3BL	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
16	SF3BT	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
16	SF3BT	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
17	SM12A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
17	SM12A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
18	SM12B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
18	SM12B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
19	SF12B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
19	SF12B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
20	SM13A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
20	SM13A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
21	SM13B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
21	SM13B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
22	SF13B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
22	SF13B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
23	SM23A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
23	SM23A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
24	SM23B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
24	SM23B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
25	SF23B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
25	SF23B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
42	SI22B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
42	SI22B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
43	SI33B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
43	SI33B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
44	SI12B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
44	SI12B	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
45	SINC	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
45	SINC	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
46	SISC	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

46 SISC 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00

NOTATION: S --- STRESS (SIGMA)
M --- MATRIX , F --- FIBER AND I --- INTERFACE
1,2,3 --- DIRECTIONS FOR STRESSES - PLY MATERIAL AXES
L,T --- DIRECTIONS OF PLY STRESSES
A --- REGION CONTAINING NO FIBERS
B --- REGION CONTAINING FIBERS AND MATRIX
EXAMPLE: SM2AL STANDS FOR TRANSVERSE NORMAL STRESS
IN REGION A DUE TO A LOAD IN THE LONGITUDINAL
DIRECTION

P A R T I C U L A T E M A T R I X
M I C R O S T R E S S E S

OVERALL MATRIX STRESS IN EACH PLY IS THE SUM OF THE
MECHANICAL, THERMAL AND MOISTURE STRESSES
COMPUTED ABOVE

NOTE: NO THERMAL OR MOISTURE STRESSES ARE PRESENT
IF PRESENT, THERMAL AND MOISTURE STRESSES ARE
SUMMED INTO 11, 22, AND 33 STRESS COMPONENTS

(NOTE: ROWS-PROPERTY, COLUMNS-LAYER)

PLY NUMBER		1	2	3	4
1	SB11A	0.6141E+03	0.6141E+03	0.6141E+03	0.6141E+03
3	SB22A	0.1844E+02	0.1844E+02	0.1844E+02	0.1844E+02
5	SB33A	0.1844E+02	0.1844E+02	0.1844E+02	0.1844E+02
7	SB12A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
9	SB13A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
11	SB23A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
13	SBVMA	0.5957E+03	0.5957E+03	0.5957E+03	0.5957E+03
15	SP11A	0.1944E+03	0.1944E+03	0.1944E+03	0.1944E+03
17	SP22A	-0.1368E+02	-0.1368E+02	-0.1368E+02	-0.1368E+02
19	SP33A	-0.1368E+02	-0.1368E+02	-0.1368E+02	-0.1368E+02
21	SP12A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
23	SP13A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
25	SP23A	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
27	SPVMA	0.2081E+03	0.2081E+03	0.2081E+03	0.2081E+03

NOTATION: S --- STRESS (SIGMA)
B---BINDER, P--- PARTICLE
VM --- VON MISES STRESS

IF PARTICULATE COMPOSITE HAS SIGNIFICANT CONTINUOUS
FIBER, STRESSES ARE BROKEN UP INTO A AND B REGIONS
FROM ABOVE. IF SIGNIFICANT CONTINUOUS FIBER IS
NOT PRESENT, A AND B REGION STRESSES ARE EQUAL

STRESSES IN BINDER REGIONS IN FRONT OF PARTICLE
ARE ASSUMED TO BE EQUAL TO THE PARTICLE STRESSES

1,2,3 --- STRESS DIRECTIONS - PLY MATERIAL AXES
L,T --- STRESS DIRECTIONS - PARTICULATE MATRIX
A --- MATRIX REGION WITH NO CONTINUOUS FIBERS
B --- MATRIX REGION WITH CONTINUOUS FIBERS

EXAMPLE: SB22B STANDS FOR TRANSVERSE NORMAL
STRESS IN BINDER OF PARTICULATE MATRIX
IN REGION B OF THE COMPOSITE

Material Databank

The constituent material properties are stored in a material databank in the same format and manner as in the ICAN code [2]. The only difference is that the particles are assumed to be isotropic, and thus equal values are put into the databank for the properties in each of the component directions. The following particle properties are provided in the databank under the fiber properties subsection in the format shown below:

PARF FILLER PARTICLES E=1/5E of IMHS.

```
$
$
$
Number of fibers per end      Nf      10000      number
Filament equivalent diameter df      0.300E-03    inches
Weight density               Rhof    0.883E-01    lb/in**3
Normal moduli (11)          Ef11    1.000E+05    psi
Normal moduli (22)          Ef22    1.000E+05    psi
Poisson"s ratio (12)        Nuf12    0.200E+00    non-dim
Poisson"s ratio (23)        Nuf23    0.200E+00    non-dim
Shear moduli (12)           Gf12    0.417E+05    psi
Shear moduli (23)           Gf23    0.417E+05    psi
Thermal expansion coef. (11) Alfaf11 3.600E-06    in/in/F
Thermal expansion coef. (22) Alfaf22 0.360E-05    in/in/F
Heat conductivity (11)      Kf11    0.868E+00    BTU-in/hr/in**2/F
Heat conductivity (22)      Kf22    0.868E+00    BTU-in/hr/in**2/F
Heat capacity                Cf      0.170E+00    BTU/lb/F
Fiber tensile strength       SfT     0.280E+06    psi
Fiber compressive strength   SfC     0.200E+06    psi
```

PAR1 SAMPLE FILLER PARTICLE 1

```
$
$
$
Number of fibers per end      Nf      10000      number
Filament equivalent diameter df      0.300E-03    inches
Weight density               Rhof    0.883E-01    lb/in**3
Normal moduli (11)          Ef11    2.000E+07    psi
Normal moduli (22)          Ef22    2.000E+07    psi
Poisson"s ratio (12)        Nuf12    0.250E+00    non-dim
Poisson"s ratio (23)        Nuf23    0.250E+00    non-dim
Shear moduli (12)           Gf12    8.000E+06    psi
Shear moduli (23)           Gf23    8.000E+06    psi
Thermal expansion coef. (11) Alfaf11 4.000E-06    in/in/F
Thermal expansion coef. (22) Alfaf22 4.000E-06    in/in/F
Heat conductivity (11)      Kf11    0.868E+00    BTU-in/hr/in**2/F
Heat conductivity (22)      Kf22    0.868E+00    BTU-in/hr/in**2/F
Heat capacity                Cf      0.170E+00    BTU/lb/F
Fiber tensile strength       SfT     0.280E+06    psi
Fiber compressive strength   SfC     0.200E+06    psi
```

PAR2 SAMPLE FILLER PARTICLE 2

```

$
$
$
Number of fibers per end      Nf      10000      number
Filament equivalent diameter df      0.300E-03    inches
Weight density                Rhof    0.883E-01    lb/in**3
Normal moduli (11)            Ef11   2.000E+07    psi
Normal moduli (22)            Ef22   2.000E+07    psi
Poisson"s ratio (12)          Nuf12   0.250E+00    non-dim
Poisson"s ratio (23)          Nuf23   0.250E+00    non-dim
Shear moduli (12)             Gf12   8.000E+06    psi
Shear moduli (23)             Gf23   8.000E+06    psi
Thermal expansion coef. (11)  Alfaf11 1.000E-06    in/in/F
Thermal expansion coef. (22)  Alfaf22 1.000E-06    in/in/F
Heat conductivity (11)         Kf11   0.868E+00    BTU-in/hr/in**2/F
Heat conductivity (22)         Kf22   0.868E+00    BTU-in/hr/in**2/F
Heat capacity                  Cf      0.170E+00    BTU/lb/F
Fiber tensile strength         SfT     0.280E+06    psi
Fiber compressive strength     SfC     0.200E+06    psi

```

The following binder properties are provided in the databank under the matrix properties subsection in the format shown below:

BIN1 SAMPLE PARTICULATE BINDER 1

```

$
$
$
Weight density                Rhom    0.440E-01    lb/in**3
Normal modulus                 Em      4.000E+06    psi
Poisson"s ratio               Num      0.150E+00    non-dim
Thermal expansion coef.       Alfa m  1.200E-05    in/in/F
Matrix heat conductivity      Km      8.681E-03    BTU-in/hr/in**2/F
Heat capacity                  Cm      0.250E+00    BTU/lb/F
Matrix tensile strength        SmT     0.150E+05    psi
Matrix compressive strength    SmC     0.350E+05    psi
Matrix shear strength         SmS     0.130E+05    psi
Allowable tensile strain       eps mT  0.200E-01    in/in
Allowable compr. strain        eps mC  0.500E-01    in/in
Allowable shear strain         eps mS  0.350E-01    in/in
Allowable torsional strain     eps mTOR 0.350E-01    in/in
Void heat conductivity         kv      0.225E+00    BTU-in/hr/in**2/F
Glass transition temperature   Tgdr    0.420E+03    F

```

BIN2 SAMPLE PARTICULATE BINDER 2

```

$
$
$
Weight density                Rhom    0.440E-01    lb/in**3
Normal modulus                 Em      4.000E+06    psi
Poisson"s ratio               Num      0.150E+00    non-dim
Thermal expansion coef.       Alfa m  4.000E-05    in/in/F
Matrix heat conductivity      Km      8.681E-03    BTU-in/hr/in**2/F

```

Heat capacity	Cm	0.250E+00	BTU/lb/F
Matrix tensile strength	SmT	0.150E+05	psi
Matrix compressive strength	SmC	0.350E+05	psi
Matrix shear strength	SmS	0.130E+05	psi
Allowable tensile strain	eps mT	0.200E-01	in/in
Allowable compr. strain	eps mC	0.500E-01	in/in
Allowable shear strain	eps mS	0.350E-01	in/in
Allowable torsional strain	eps mTOR	0.350E-01	in/in
Void heat conductivity	kv	0.225E+00	BTU-in/hr/in**2/F
Glass transition temperature	Tgdr	0.420E+03	F

In addition to the particles and binders listed above, all of the fiber and matrix properties that are present in the default databank of the original ICAN are present in ICAN/PART. Additionally, the user can add any materials desired to the databank by adding a dataset, using the appropriate format, to the appropriate area of the databank (fiber subsection for fibers or particles, matrix subsection for matrices or binders). As in the original ICAN, the properties in the material databank are accessed by specifying the appropriate four letter code names in the input deck. As mentioned in an earlier section, the material databank must be given the UNIX file name "databk.dat" and be located in the same directory as the executable of the ICAN/PART code.

VERIFICATION OF ICAN/PART CODE

Due to the approximate nature of the micromechanics equations programmed into ICAN/PART [1], a quantitative verification of the computed results was conducted to ensure that the micromechanics included in ICAN/PART model the mechanics of the problem correctly. Specifically, three dimensional finite element and boundary element analyses of a representative volume element were performed. The particle was the "PAR1" particle from the material databank, and the binder was the "BIN1" binder. A particle volume fraction of 0.3 was utilized, and no continuous fibers were present in the composite.

For the finite element analysis, the finite element code MSC/NASTRAN [4] was utilized. The particulate composite was modeled by embedding a cube of dimensions 1" X 1" X 1" (the particle) into another cube of dimensions 1.5" X 1.5" X 1.5". A composite with a particle volume fraction of 0.3 was thus modeled. Even though an actual particle would not necessarily have a cubed shape, this geometry was chosen since the micromechanics equations in ICAN/PART assume such a shape for the representative volume element. By utilizing a cubed particle shape in the finite element analysis, full compatibility between the ICAN/PART micromechanics and the finite element model is ensured. A cut-away view of the finite element model (with the cutting plane at halfway through the thickness) is shown in Figure 3. This cut-away view shows how the particle is embedded in the binder. Eight noded brick elements were used for the finite element mesh. The particle was meshed with 64 elements, and the total number of elements for the composite was 1000. The model is subjected to both mechanical and thermal loads. The boundary conditions imposed for the mechanical loads case include an enforced uniform displacement on one side of the model ($X=1.5$ "), while the other side ($X=0$ ") is fixed in all three coordinate directions. The resulting nodal forces are then obtained from the finite element analysis, which are then summed and averaged on the face where the enforced displacements were imposed. For this particular analysis, the average nodal force turned out to be 426 psi. The average nodal force is then divided by the cross-sectional area to obtain the average stress resulting from the applied uniform strain. The equivalent modulus of the composite can then be calculated from this information. To compute the equivalent thermal expansion coefficient, a uniform temperature increase of 100 deg. F was applied to the model, and the resulting average displacement on a cross section of interest was determined. From this information, the average strain due to thermal loading on the cross-section was determined, and the thermal expansion coefficient for the composite was then calculated.

For the boundary element analysis, the NASA Lewis developed boundary element analysis code BEST-CMS [5] was utilized to analyze the composite. The geometry and dimensions for the boundary element model are identical to what was used for the finite element model. A cut-away view of the boundary element mesh is shown in

Figure 4, in which portions of the binder mesh were cut away in order to display the particle. In discretizing the model, the major difference between the boundary element method and the more commonly utilized finite element method is that while for the finite element method the entire volume of a domain is discretized using volume elements, with the boundary element method only the outer surface of the domain is discretized using surface elements. For this analysis, 54 eight noded quadrilateral surface elements were used to mesh the particulate, and the total number of elements for the composite was 162. An important point to note is that only the outer surface of the cube representing the particulate and the cube representing the surrounding matrix are discretized. Another important point to note is that with the boundary element methodology acceptable results can be obtained using a much coarser mesh than is required for an equivalent finite element model.

To compute the average modulus using BEM, an applied traction (pressure) load equal to the average nodal load determined in the finite element analysis was applied to one face ($Z=1.5''$) of the composite, while roller constraints were applied to the $X=0$, $Y=0$ and $Z=0$ faces. The average nodal displacement (and thus the average strain), was then computed on the face on which the traction load was applied. The effective modulus was computed using the applied traction load and the resulting average nodal strain. The effective thermal expansion coefficient was computed by applying a uniform temperature increase of 100 deg. F to the model, and then computing the average nodal displacement (and thus strain) on the $Z=1.5''$ face of the model. The manner in which the effective properties were computed for the boundary element model differs somewhat from that utilized for the finite element model since the current version of the boundary element analysis software does not permit multi-point constraint boundary conditions. Additionally, the most accurate results are computed on the outer surfaces of the boundary element model.

As part of the finite element analyses, microstresses were also computed in the constituents of the particulate matrix composite in order to allow a comparison to the values computed in ICAN/PART. In general, the three dimensional stresses computed by a finite element analysis vary significantly throughout the model. In order to consistently compare these values to the values computed by ICAN/PART, which are the "average" stresses in each constituent, the stresses computed by the finite element method must be averaged in various regions in each constituent of the composite. Stress calculations for the interior of the model were not available for the boundary element model due to current limitations in the boundary element analysis software which do not allow detailed calculations of stress states in the interior of the model.

The equivalent composite properties computed utilizing the various analysis methods are presented in the table below.

Property	Boundary Element	ICAN/PART	Finite Element
Modulus, Msi	5.9	6.1	6.4
Poisson's Ratio	.179	.17	.164
Shear Modulus, Msi	-----	2.6	2.74
Coeff. of Thermal Exp. E-06 in/in/F	8.5	8.6	8.94

The effective properties computed by ICAN/PART compare favorably to both the finite element and boundary element results. Additionally, the ICAN/PART results fall within bounds established by the boundary element and finite element results. These results indicate that ICAN/PART is adequately modeling the mechanics and computing the equivalent properties with acceptable accuracy. Additionally, ICAN/PART can compute these values in a fraction of the time required to conduct detailed finite element or boundary element analyses.

The stresses in the particle and the binder due to both mechanical and thermal loading are shown in the table below. The mechanical and thermal loads were applied separately, in separate analyses. The mechanical load was an axial load of 426 psi, which is identical to the load utilized in computing the effective properties. The thermal load was a uniform temperature increase of 100 deg. F. Results computed using both ICAN/PART and the finite element method are included. It is important to note that the stresses listed for the finite element results are the average stresses over the constituent, and that the actual stress state varies over the constituent. The loading levels are identical to those discussed above in the micromechanics predictions section.

Stress (psi)	ICAN/PART	Finite Element
Particle: Mechanical Load	604.7	580
Binder: Mechanical Load	280.9	265
Particle: Thermal Load	2075	1000-3000
Binder: Thermal Load	1412	1600

The stress results computed by ICAN/PART compare fairly well to the results computed by the finite element method, with the results due to mechanical loading falling within 7% of each other. In ICAN/PART, due to the approximations involved in

deriving the microstress equations the computed results are only average values over the constituent, while in reality the stress state varies considerably over the entire range of the representative volume element. Additionally, continuity in stress states is not imposed between the various regions of the unit cell. For the finite element model, modeling the particulate as a cube may have introduced stress concentrations at the corners that may not be present in the actual material (and are not accounted for in the ICAN/PART derivations). Overall, if an analyst is interested in obtaining preliminary information on the order of magnitude of stresses that will be found in a particulate composite due to a given load state, ICAN/PART appears to give reasonable answers. If a user is interested in more detailed information about the specific stress levels in specific locations of the composite, a detailed finite element model could then be constructed and analyzed.

CONCLUSIONS

The ICAN/PART computer code has been developed in order to predict the effective properties and constituent microstresses for particulate reinforced composites. ICAN/PART is based and derived from the ICAN computer code, which was developed in order to conduct micromechanical analyses of fiber reinforced polymer matrix composites. Details of the input and output, along with examples, have been presented. Effective properties computed using ICAN/PART were found to compare favorably to results computed using detailed three dimensional finite element and boundary element analyses. Microstresses computed using ICAN/PART compared favorably in an average sense with results computed using finite element analyses. These results indicate that the micromechanics equations programmed into ICAN/PART model the mechanics of the problem correctly. However, the microstresses computed by ICAN/PART should be seen only as preliminary, averaged results.

Immediate goals for future work will involve adding to ICAN/PART the capability to account for the effects of moisture on both the effective properties and the microstresses. In addition, the capability to account for an interfacial region between the fiber and the matrix will be included. Such interfacial regions have been found to frequently exist in particulate reinforced composites, and can strongly effect the effective properties, particularly the effective strength. Overall, capabilities to predict the effective composite strength will be included. Longer term efforts may involve adding the capability to incorporate cyclic loading conditions. Additionally, longer term efforts may involve adding the capability to incorporate uncertainties in the material properties through the use of probabilistic approaches.

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5. Henry, D.P.; Banerjee, P.K.; and Dargush, G.F.: Development of Boundary Element Methods for Ceramic Composites. NASA Contractor Report 195326, NASA Lewis, 1994.

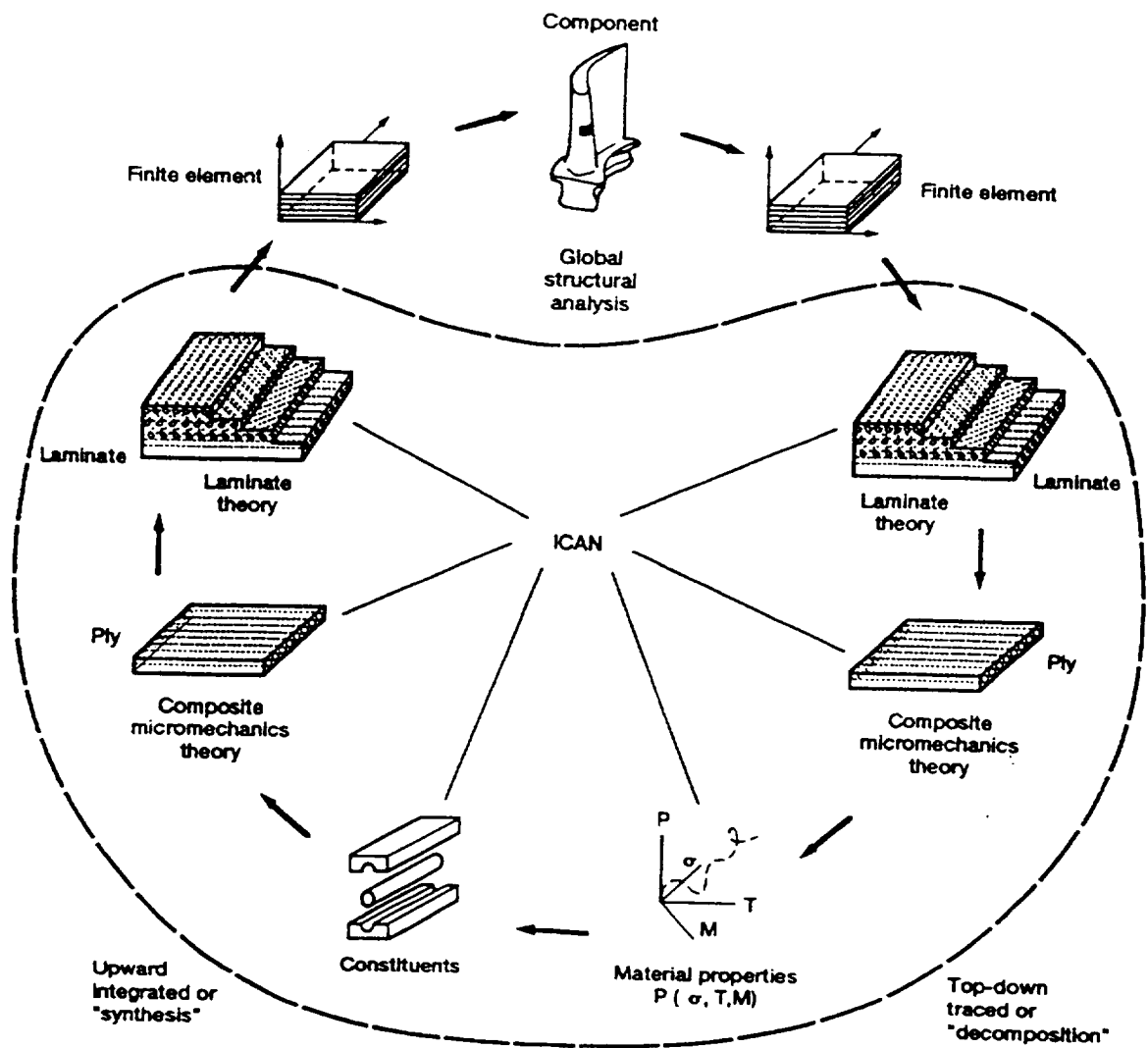


Figure 1: Flowchart showing the integrated analysis approach included in ICAN.

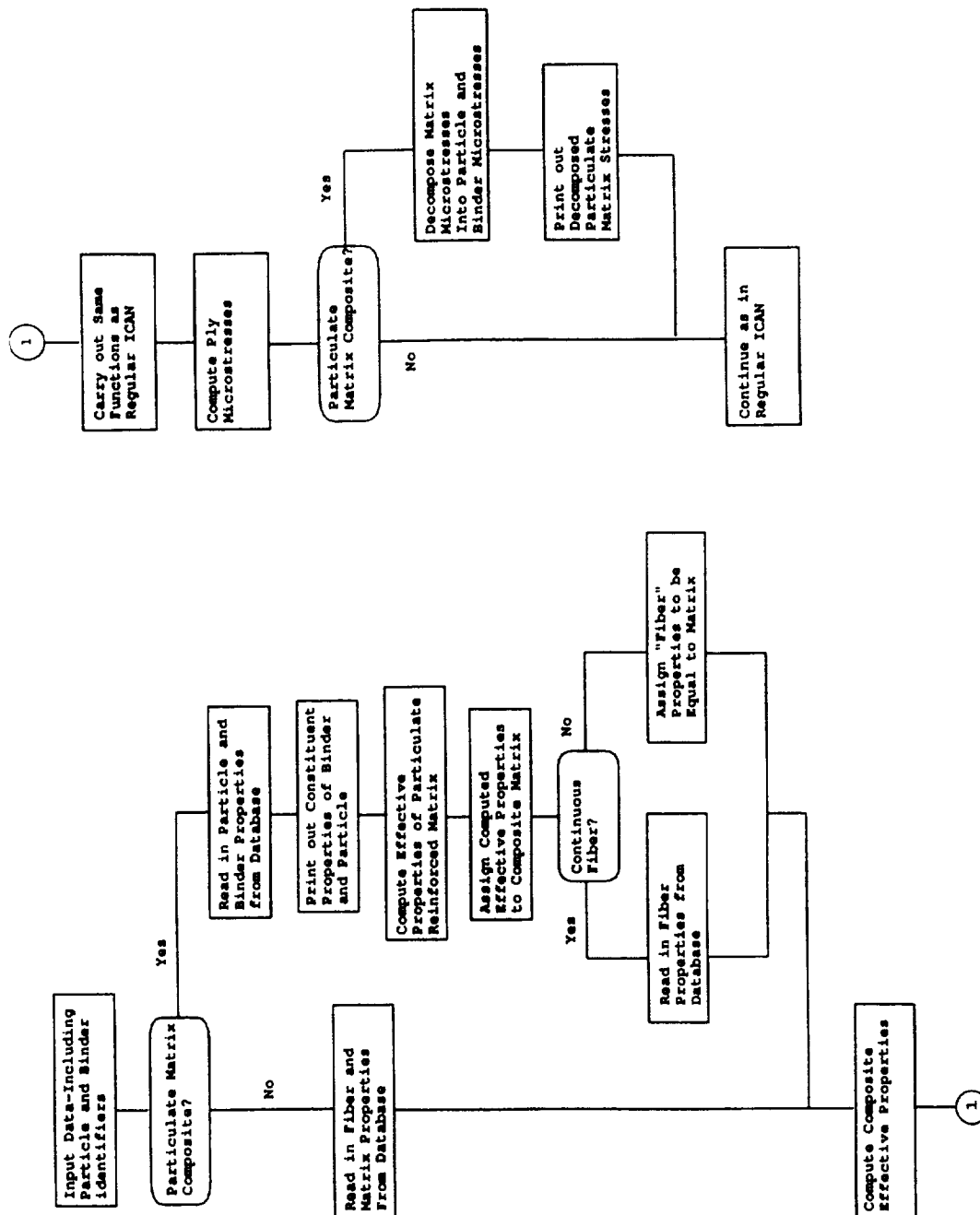


Figure 2: Flowchart showing specifics of ICAN/PART execution.

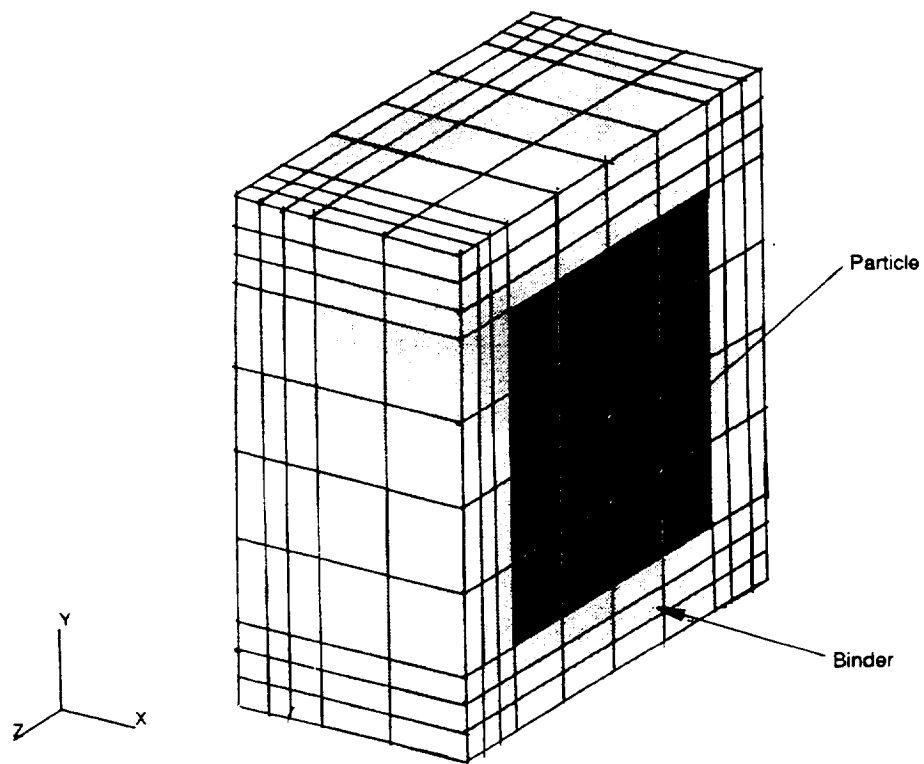


Figure 3: Cross-sectional view of 3-D FEM model of particulate composite unit cell.

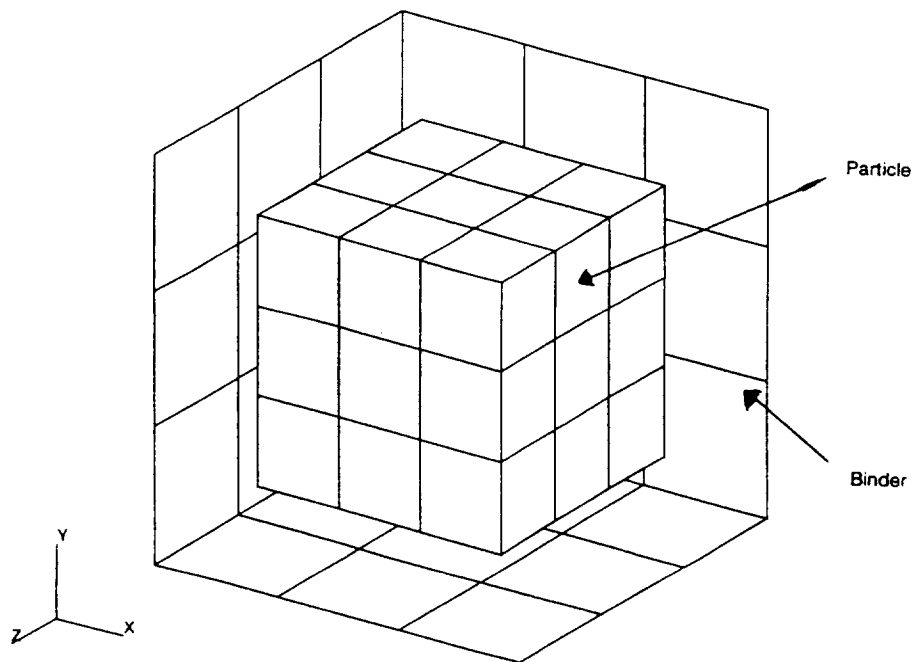


Figure 4: Cut-away view of 3-D BEM model of particulate composite unit cell

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13. ABSTRACT (Maximum 200 words) A methodology for predicting the equivalent properties and constituent microstresses for particulate matrix composites, based on the micromechanics approach, is developed. These equations are integrated into a computer code developed to predict the equivalent properties and microstresses of fiber reinforced polymer matrix composites to form a new computer code, ICAN/PART. Details of the flowchart, input and output for ICAN/PART are described, along with examples of the input and output. Only the differences between ICAN/PART and the original ICAN code are described in detail, and the user is assumed to be familiar with the structure and usage of the original ICAN code. Detailed verification studies, utilizing three dimensional finite element and boundary element analyses, are conducted in order to verify that the micromechanics methodology accurately models the mechanics of particulate matrix composites. The equivalent properties computed by ICAN/PART fall within bounds established by the finite element and boundary element results. Furthermore, constituent microstresses computed by ICAN/PART agree in average sense with results computed using the finite element method. The verification studies indicate that the micromechanics programmed into ICAN/PART do indeed accurately model the mechanics of particulate matrix composites.				
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